

Fireballs and meteor showers as seen by the NASA All Sky Fireball Network

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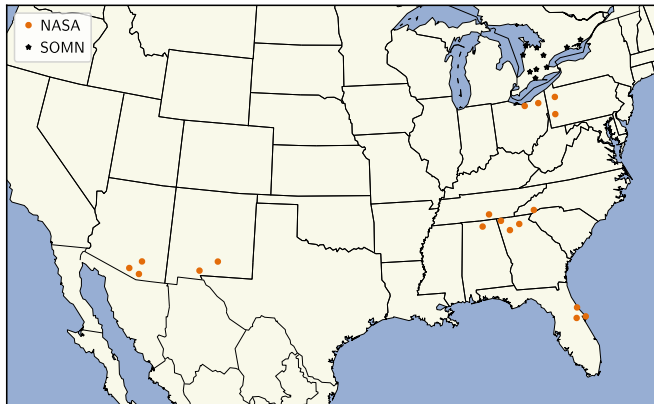
Outline

- ▶ Overview of all-sky network and data
- ▶ Discussion of shower and sporadic meteors
- ▶ Past and current projects that use all-sky data
- ▶ Potential student projects

All-sky meteor camera and sample image



Map



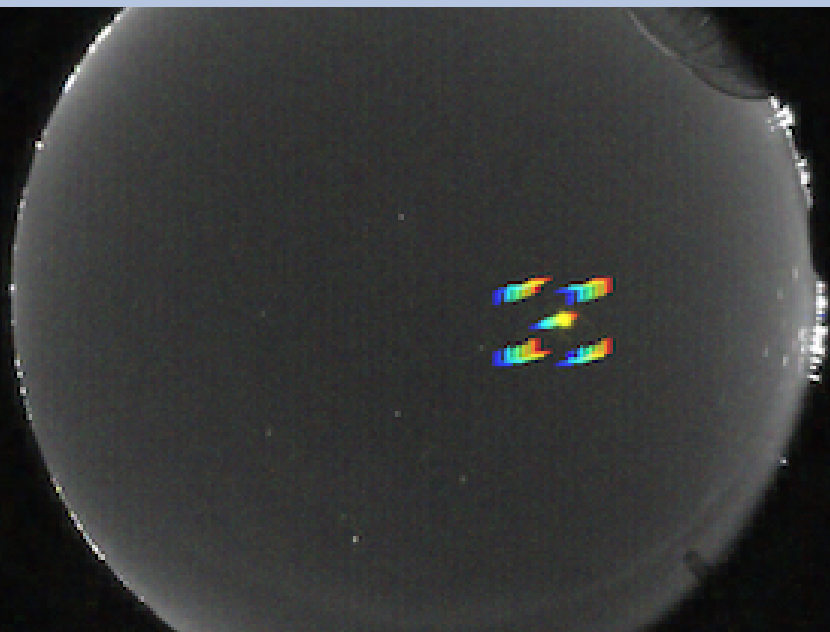
Meteor detection



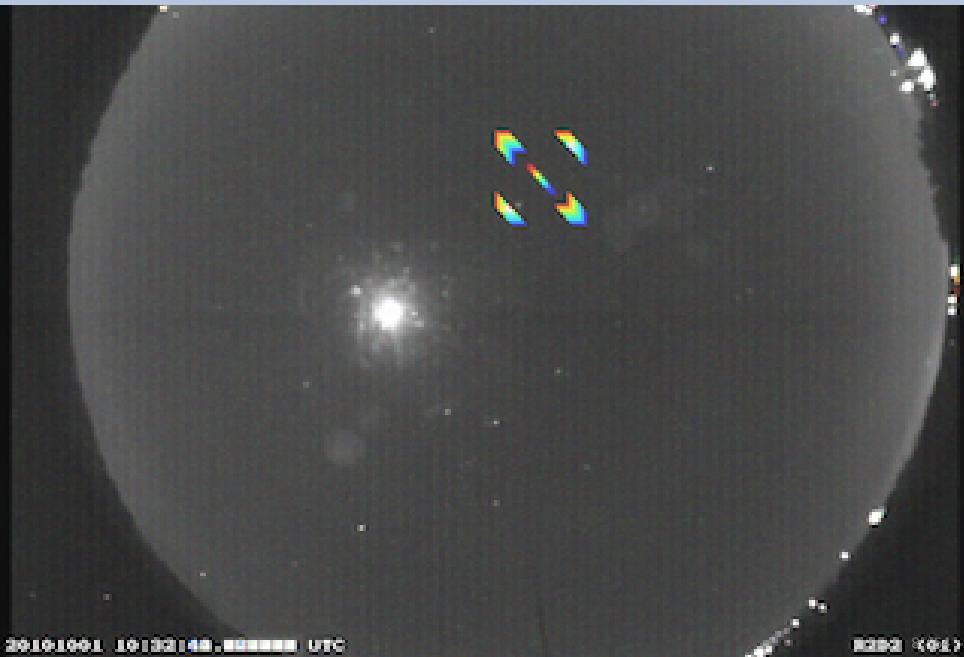
Meteor detection



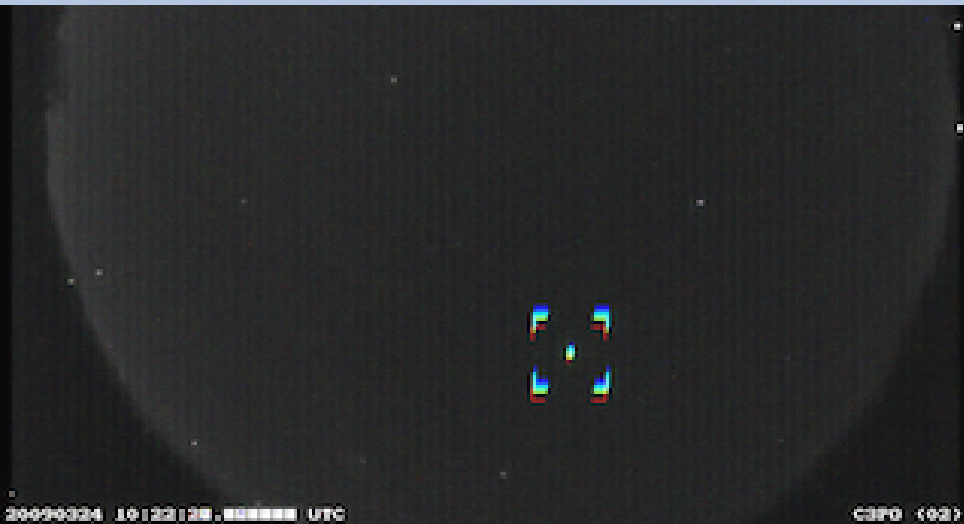
Meteor detection



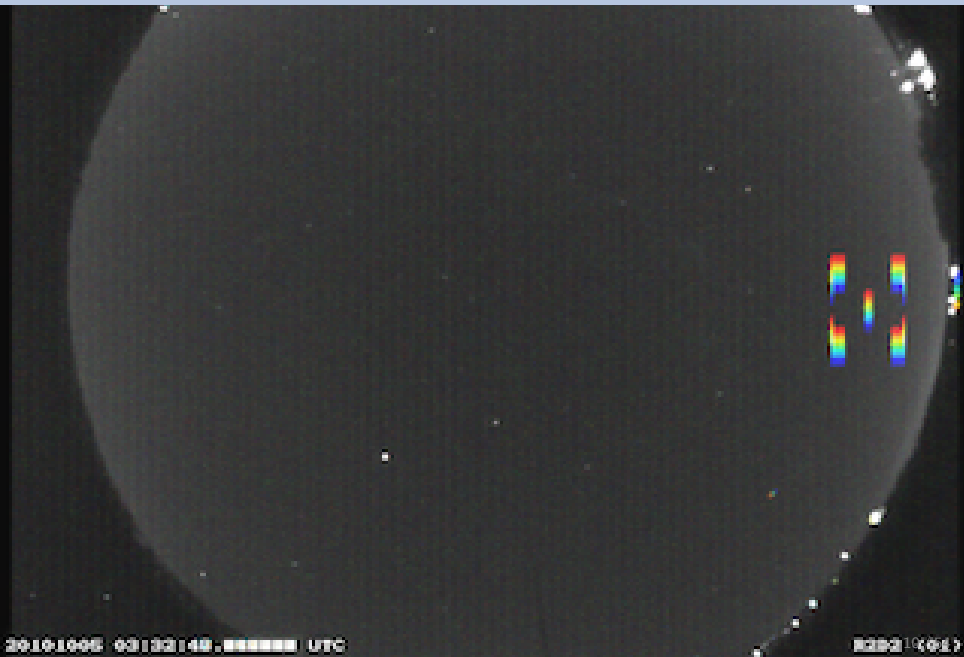
False positives: satellites (ISS)



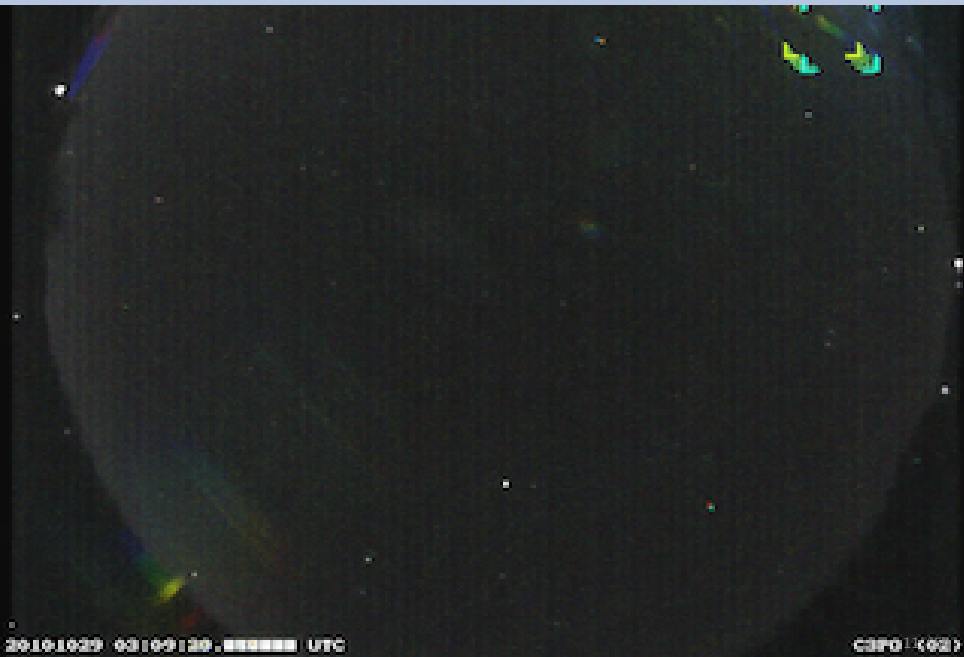
False positives: satellites (Iridium Flare)



False positives: airplanes



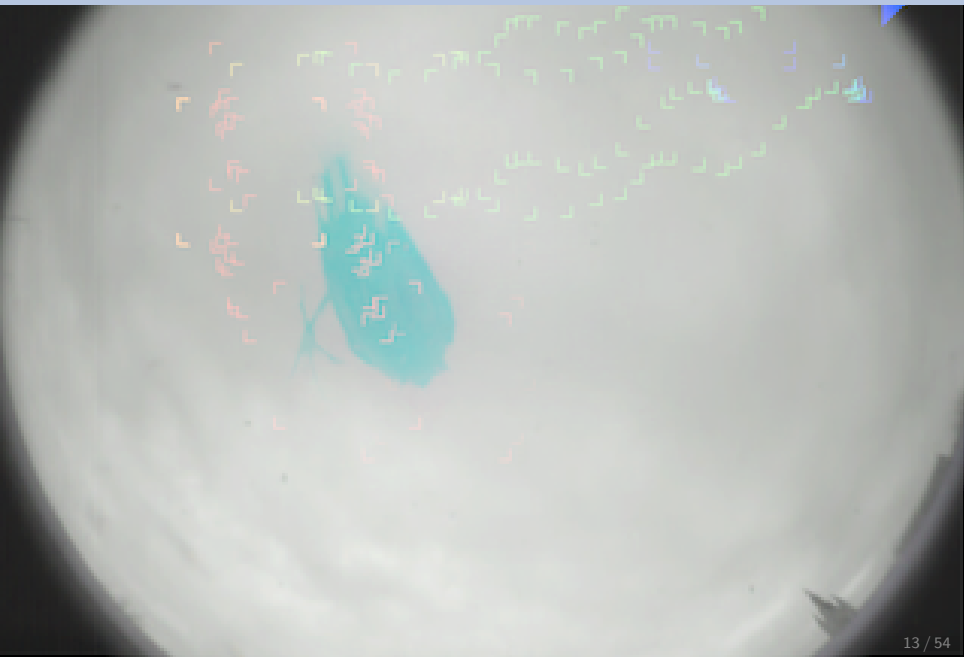
False positives: vehicle headlights



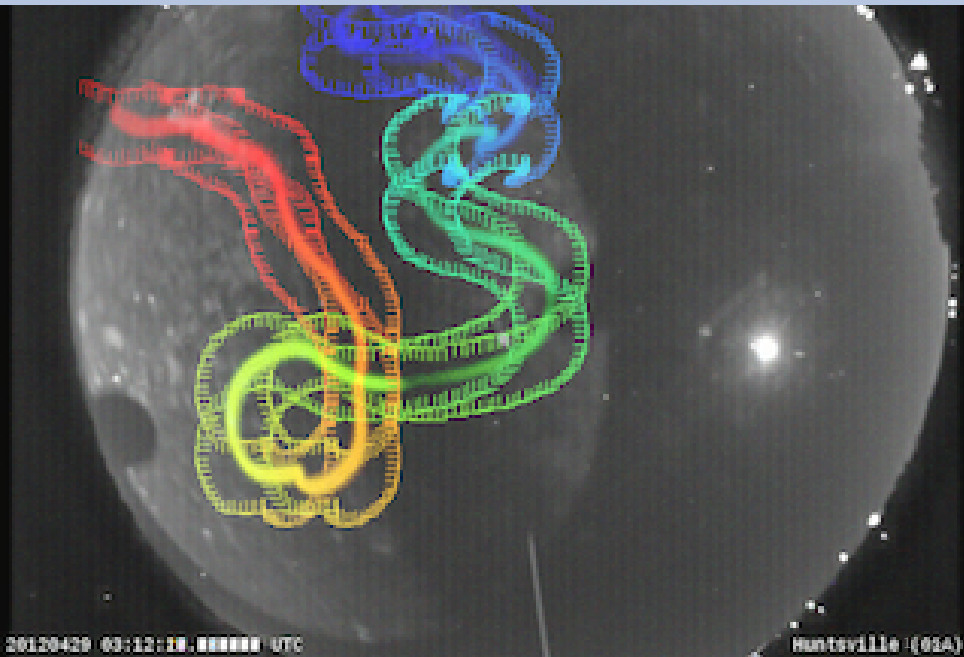
False positives: lightning



False positives: birds



False positives: insects and spiders



False positives

- ▶ Satellites: too high
- ▶ Airplanes: too low
- ▶ Headlights: only one camera
- ▶ Lightning: too low, track is erratic
- ▶ Birds and bugs: only one camera, track is erratic

Meteor detection: false negatives

- ▶ We get false negatives as well (meteors that are rejected)
- ▶ We review these rejects near-daily and override as needed
- ▶ These show up in the log more than a day later

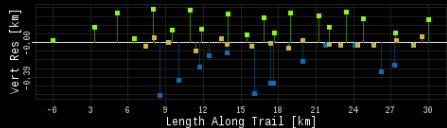
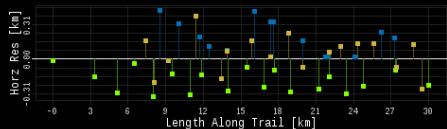
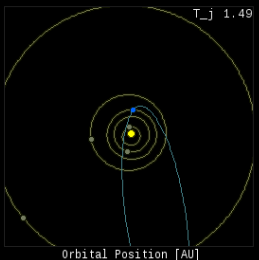
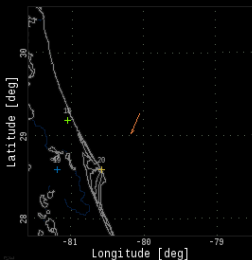
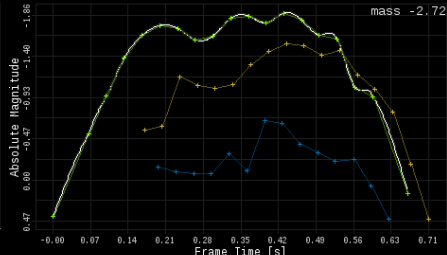
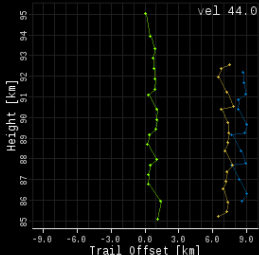
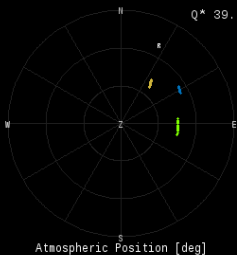
Event data

20171218 04:22:37 UTC

$Q^* 39.2$

vel 44.0

mass -2.72

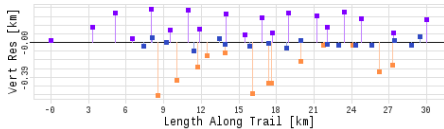
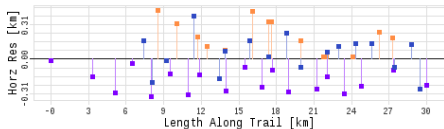
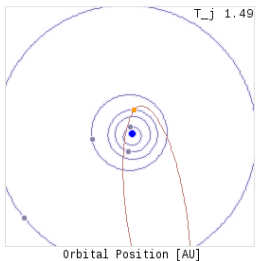
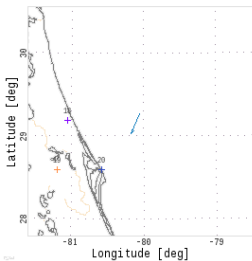
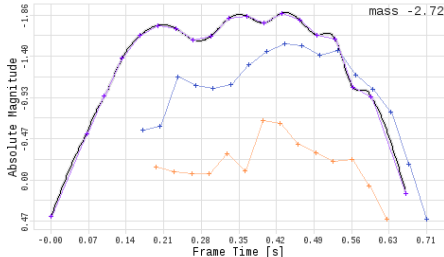
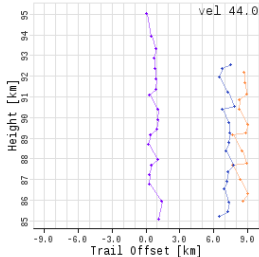
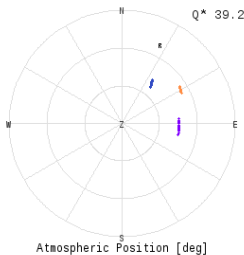


Event data

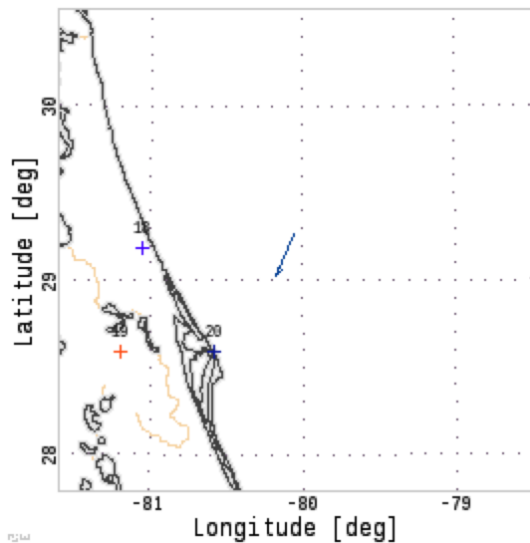
20171218 04:22:37 UTC



...



Camera stations

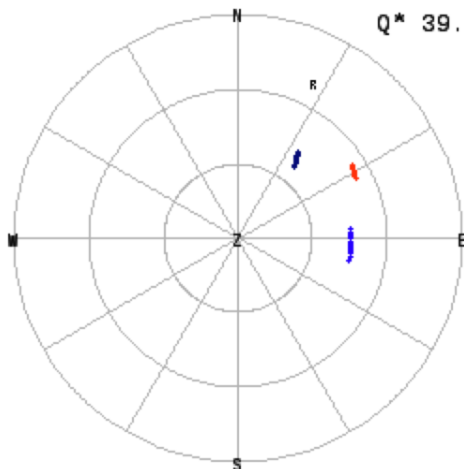


Position relative to cameras

20171218 04:22:37 UTC

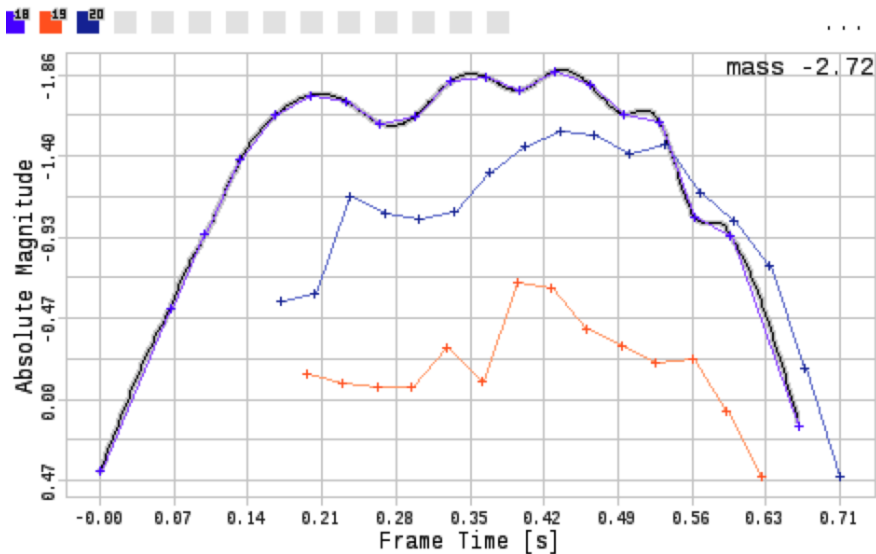


Q* 39.2

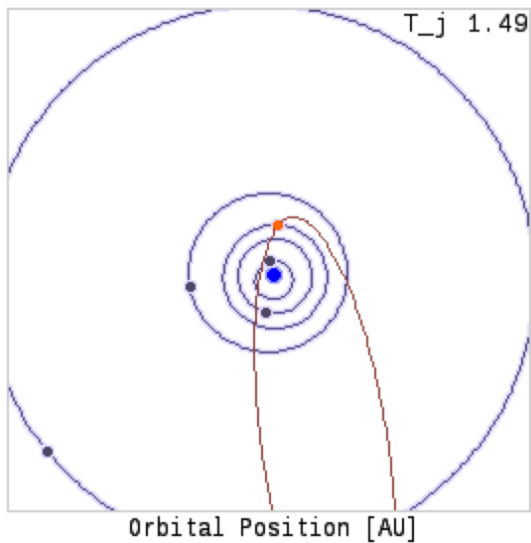


Atmospheric Position [deg]

Brightness



Orbit



Orbit

```
time 20180108 4.7600 hours
lat 33 22 29.208 = 33.3748 deg
lon 250 53 24.216 = 250.8901 deg
ht 54.610 b -14.07390 7.06982 -5.75963 19.87105
    alp 84.870 +/- 19.112 deg
    del 22.386 +/- 10.702 deg
    v_inf 21.555 +/- 2.256 km/s
    v_avg 21.555 +/- 2.256 km/s

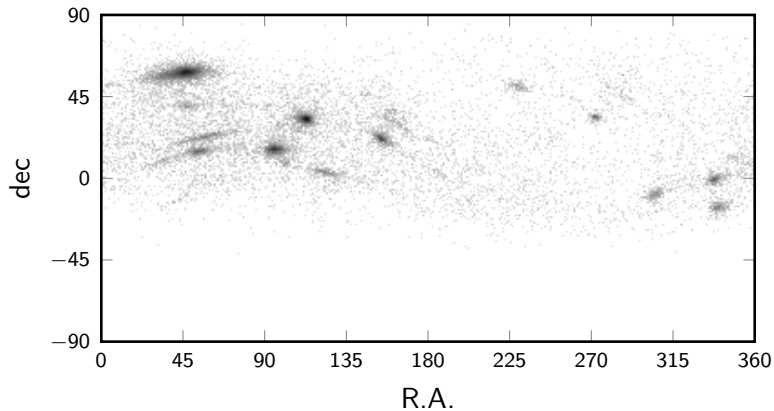
    a 7.214 +/- 22.675 AU
    e 0.888 +/- 0.338
    incl 0.863 +/- 5.700 deg
    omega 51.721 +/- 23.497 deg
asc_node 107.747 +/- 0.979 deg
    v_g 18.350 +/- 2.643 km/s
    v_h 41.004 +/- 4.713 km/s
alp_geo 84.476 +/- 20.584 deg
del_geo 21.582 +/- 11.588 deg
    q_per 0.806 +/- 0.118 AU
    q_aph 13.622 +/- 45.252 AU
    lambda 85.120 +/- 19.140 deg
    beta -1.757 +/- 11.604 deg
true_anom 308.131 +/- 11.604 deg

T_j 1.8
```

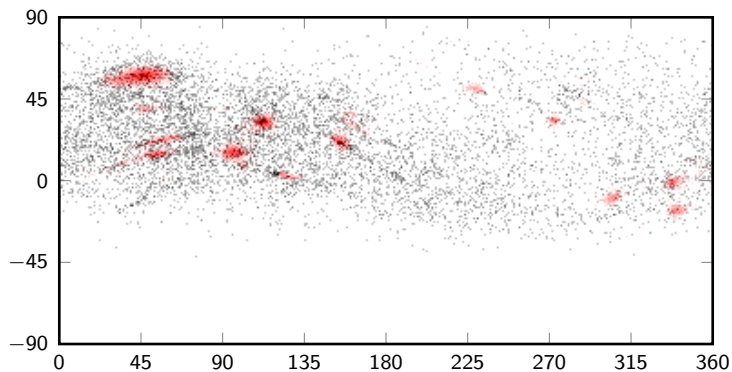
Shower vs. sporadic meteors

- ▶ It is a common misconception that all or most meteors belong to meteor showers.
- ▶ Showers have steeper mass indices and are more important at large sizes.
- ▶ But sporadic meteors are the majority even at fireball sizes: 2/3 of all-sky detections are classed as sporadic

Shower vs. sporadic

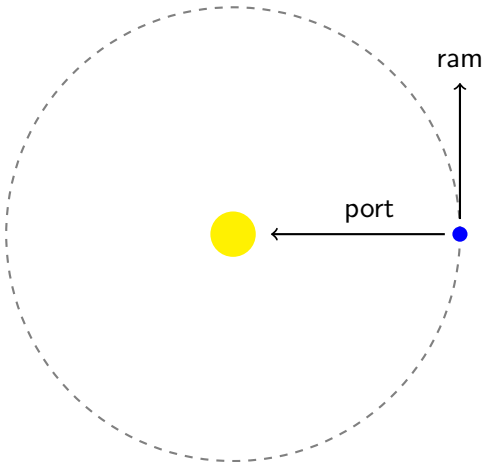


Shower vs. sporadic

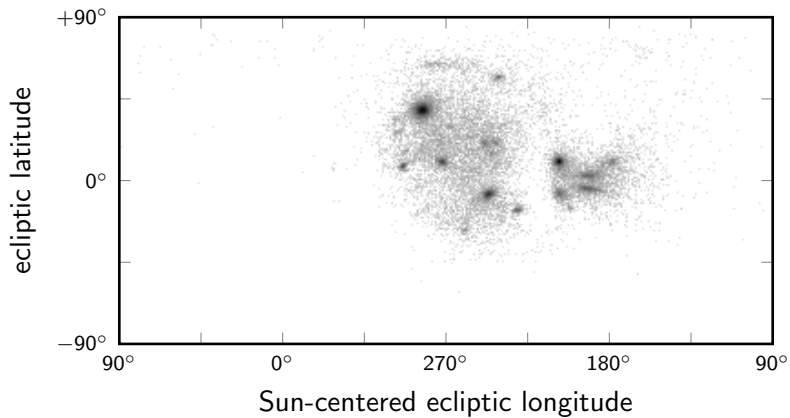


Sun-centered ecliptic coordinates

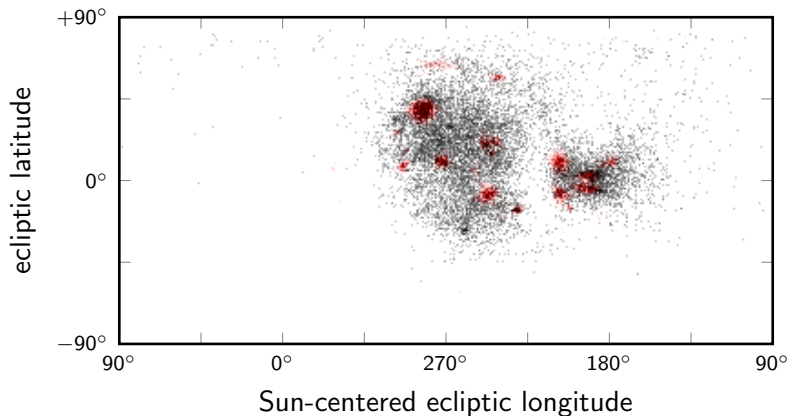
$\lambda - \lambda_{\odot}, \beta$



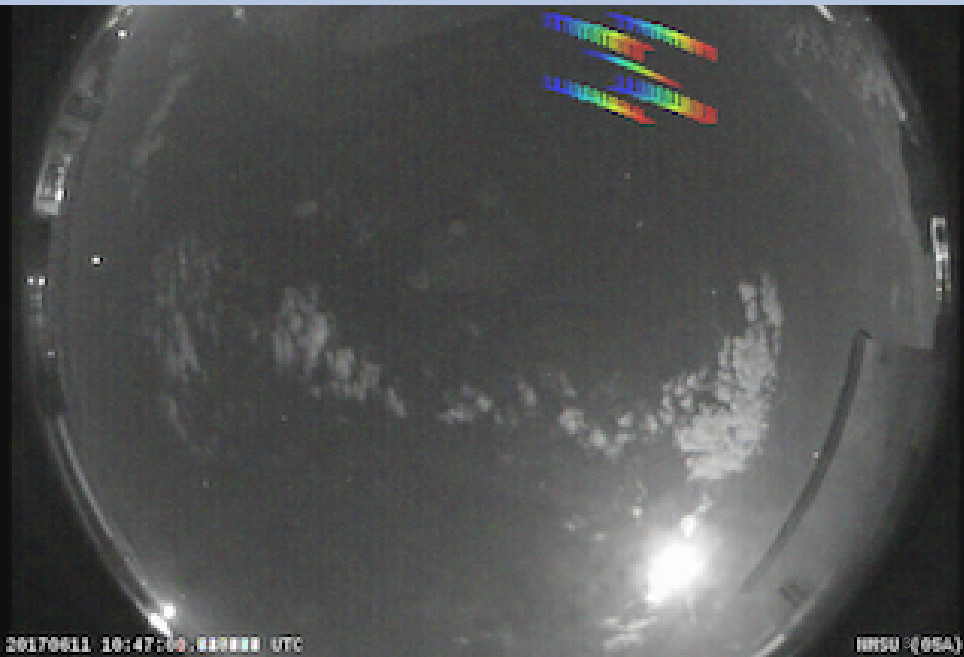
Shower vs. sporadic



Shower vs. sporadic



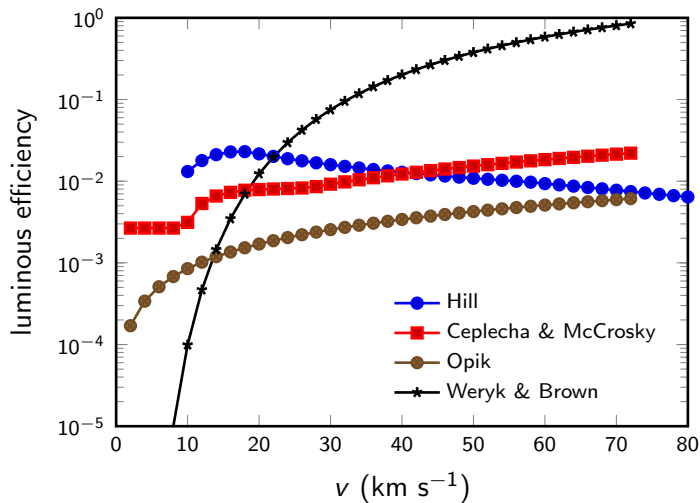
Daytime showers



20170611 10:47:10.000000 UTC

IMSU 3(USA)

What you see is *not* an unbiased sample



Meteor Data Center: 821 showers as of 7 Dec 2017

00006	LYR	April Lyrids	00223	GV1	Daytime gamma Virginids	00409	NCY	nu Cygnids	00599	POS	72 Ophiuchids
00007	PER	Perseids	00224	DAU	October delta Aurigids	00410	DPI	delta Piscids	00600	FAU	43 Aurigids
00008	ORI	Orionids	00225	SOR	sigma Orionids	00411	CAN	c Andromedids	00601	ICT	iota Craterids
00009	DRA	October Draconids	00226	ZTA	zeta Taurids	00412	FOP	f Ophiuchids	00602	KCR	kappa Craterids
00010	QUA	Quadrantids	00227	OMO	October Monocerotids	00413	MUL	mu Lyrids	00603	FRC	15 Cancrids
00011	IVI	eta Virginids	00228	OLY	October Lyncids	00414	ATR	alpha Triangulids	00604	ACZ	zeta1 Acanids
00012	KCG	kappa Cygnids	00229	NAU	nu Aurigids	00415	AUP	August Piscids	00605	FHR	52 Herculis
00013	LEO	Leonids	00230	ICS	October iota Cassiopeids	00416	SIC	September iota Cassiopeids	00606	JAU	January alpha Ursae Majorids
00014	XOR	chi Orionid Complex	00231	ACM	Daytime alpha Canis Majorids	00417	ETT	eta Taurids	00607	TBO	12 Bootids
00015	URS	Ursids	00232	BCN	Daytime beta Cancriids	00418	BHE	beta Herculis	00608	FAR	14 Aurigids
00016	HYD	sigma Hydrids	00233	OPC	October Capricornids	00419	DAC	Daytime April Cetids	00609	BOT	37 Comae Berenicids
00017	NTA	Northern Taurids	00234	ECC	October epsilon Piscids	00420	CCA	chi Capricornids	00610	SGM	68 Geminids
00018	AND	Andromedids	00235	LCY	lambda Cygnids	00421	MMI	May Microscopids	00611	VCF	4 Canum Veneticids
00019	MON	December Monocerotids	00236	GPS	gamma Piscids	00422	NLL	Northern Librids-Lupids	00612	NCA	19 Canum Veneticids
00020	COM	Comae Berenicids	00237	SSA	sigma Arietids	00423	SLL	Southern Librids-Lupids	00613	TLY	31 Lyncids
00021	AVB	alpha Virginids	00238	DOR	alpha Doradids	00424	SOL	September-October Lyncids	00614	JOS	January omega Serpentids
00022	LMI	Leonis Minorids	00239	GPU	October gamma Puppids	00425	PSA	psi Aurigids	00615	TOR	35 Comae Berenicids
00023	EGE	epsilon Geminids	00240	DFV	Daytime psi Virginids	00426	DCR	Daytime Craterids	00616	TOB	26 Comae Berenicids
00025	NQA	Northern October delta Arietids	00241	OUI	October Ursae Minorids	00427	FED	February eta Draconids	00617	IUM	iota Ursae Majorids
00026	NDA	Northern delta Aquarids	00242	XDR	xi Draconids	00428	DSV	December sigma Virginids	00618	THD	12 Hydrids
00027	KSE	kappa Serpentids	00243	ZCN	zeta Cancriids	00429	ACB	alpha Coronae Borealis	00619	SLM	7 Leonis Minorids
00028	SQA	Southern October delta Arietids	00244	PAR	psi1 Aurigids	00430	POR	September pi Orionids	00620	SBO	sigma Bootids
00029	DLE	delta Leonid Complex	00245	NHD	November Hydrids	00431	JIP	June iota Pegasids	00621	SJA	73 Ursae Majorids
00030	PSC	Piscid Complex	00246	AMO	alpha Monocerotids	00432	NBO	nu Bootids	00622	PJA	phi Ursae Majorids
00031	ETA	eta Aquarids	00247	TAU	Taurid Complex	00433	ETP	eta Pegasids	00623	XTC	xi2 Capricornids
00033	NIA	Northern iota Aquarids	00249	NAR	November nu Arietids	00434	BAR	beta Arietids	00624	XAR	xi Arietids
00034	DSE	delta Serpentids	00250	NOO	November Orionids	00435	MPR	mu Perseids	00625	LTA	lambda Taurids
00038	CUR	xi Ursae Majorids	00251	IVI	Daytime iota Virginids	00436	GCP	gamma Cepheids	00626	LCT	lambda Cetids
00039	NAL	Northern alpha Leonids	00252	ALY	alpha Lyncids	00437	NLY	November Lyncids	00627	MPI	mu Piscids
00040	ZCY	zeta Cygnids	00253	CMI	December Canis Minorids	00438	MLE	mu Leonids	00628	STS	s Taurids
00043	ZSE	zeta Serpentids	00254	PHO	Phoenicids	00439	ASX	alpha Sextantids	00629	ATS	A2 Taurids
00045	PDF	phi Draconids	00255	PUV	Puppil-Velid I Complex	00440	NLM	November Leonis Minorids	00630	TAT	tau Arietids
00046	BCR	beta Craterids	00256	ORN	Northern chi Orionids	00441	NLD	November lambda Draconids	00631	DAT	delta Arietids
00047	DLI	mu Virginids	00257	ORS	Southern chi Orionids	00442	RLE	rho Leonids	00632	NET	November eta Taurids
00049	LVI	lambda Virginids	00258	DAR	December alpha Aurigids	00443	DCL	December Leonids	00633	PTS	p Taurids
00050	VIR	March Virginid Complex	00259	CAR	Carinid Complex	00444	ZCS	zeta Cassiopeids	00634	TAT	tau Taurids
00052	OUM	omega Ursae Majorids	00260	GTI	gamma Triangulids	00445	KUM	kappa Ursae Majorids	00635	ATU	A1 Taurids
00061	TAH	tau Herculis	00261	DDC	Daytime delta Scorpids	00446	DPC	December phi Cassiopeids	00636	MTA	m Taurids
00063	COR	Corvids	00262	KLI	Daytime kappa Librids	00448	AAL	April alpha Librids	00637	FTR	f Taurids
00065	GDE	gamma Delphinids	00263	NAN	nu Andromedids	00449	ABS	April beta Sextantids	00638	DZT	December zeta Taurids
00066	NSC	Northern omega Scorpids	00264	XCE	xi Cetids	00450	AED	April epsilon Delphinids	00640	AOA	August omicron Aquarids
00067	NSA	Northern mu Sagittarids	00265	JGD	January gamma Delphinids	00451	CAM	Camelopardalids	00641	DRG	December rho Geminids

International Meteor Organization (IMO): 37 showers in 2018 calendar

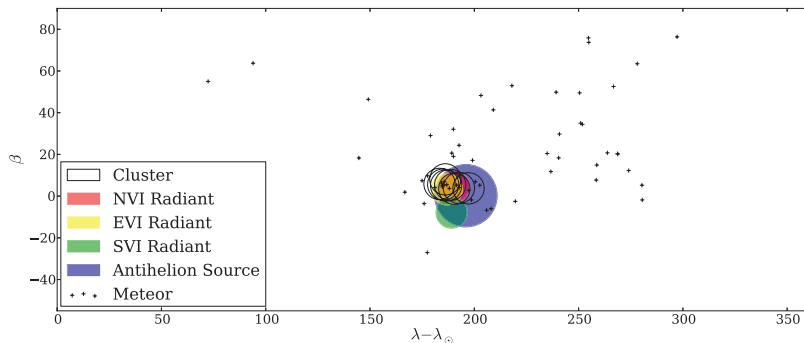
Shower	Activity	Maximum Date	λ_{\odot}	Radiant α	δ	V_{∞} km/s	r	ZHR
Antihelion Source (ANT)	Dec 10–Sep 10 –	March–April, late May, late June		see Table 6		30	3.0	4
Quadrantids (010 QUA)	Dec 28–Jan 12	Jan 03	283°15'	230°	+49°	41	2.1	110
γ -Ursae Minorids (404 GUM)	Jan 10–Jan 22	Jan 18	298°	228°	+67°	31	3.0	3
α -Centaurids (102 ACE)	Jan 31–Feb 20	Feb 08	319°2'	210°	−59°	58	2.0	6
γ -Normids (118 GNO)	Feb 25–Mar 28	Mar 14	354°	239°	−50°	56	2.4	6
Lyrids (006 Lyr)	Apr 14–Apr 30	Apr 22	32°32'	271°	+34°	49	2.1	18
π -Puppids (137 PPU)	Apr 15–Apr 28	Apr 23	33°5'	110°	−45°	18	2.0	Var
η -Aquariids (031 ETA)	Apr 19–May 28	May 06	45°5'	338°	−01°	66	2.4	50
η -Lyrids (145 ELY)	May 03–May 14	May 09	48°0'	287°	+44°	43	3.0	3
Dayt. Arietids (171 ARI)	May 14–Jun 24	Jun 07	76°6'	44°	+24°	38	2.8	30
June Bootids (170 JBO)	Jun 22–Jul 02	Jun 27	95°7'	224°	+48°	18	2.2	Var
Piscis Austr. (183 PAU)	Jul 15–Aug 10	Jul 28	125°	341°	−30°	35	3.2	5
S. δ -Aquariids (005 SDA)	Jul 12–Aug 23	Jul 30	127°	340°	−16°	41	2.5	25
α -Capricornids (001 CAP)	Jul 03–Aug 15	Jul 30	127°	307°	−10°	23	2.5	5
Perseids (007 PER)	Jul 17–Aug 24	Aug 12	140°0'	48°	+58°	59	2.2	110
κ -Cygnids (012 KCG)	Aug 03–Aug 25	Aug 18	145°	286°	+59°	25	3.0	3
Aurigids (206 AUR)	Aug 28–Sep 05	Sep 01	158°6'	91°	+39°	66	2.5	6
Sep. ε -Perseids (208 SPE)	Sep 05–Sep 21	Sep 09	166°7'	48°	+40°	64	3.0	5
Dayt. Sextantids (221 DSX)	Sep 09–Oct 09	Sep 27	184°3'	152°	+00°	32	2.5	5
Oct. Camelopard. (281 OCT)	Oct 05–Oct 06	Oct 06	192°58'	164°	+79°	47	2.5	5
Draconids (009 DRA)	Oct 06–Oct 10	Oct 09	195°4'	262°	+54°	20	2.6	10
S. Taurids (002 STA)	Sep 10–Nov 20	Oct 10	197°	32°	+09°	27	2.3	5

... plus 11 daytime showers

Shower	Activity	Max Date	λ_{\odot} 2000	Radiant α δ		Rate
Capricornids/Sagittariids (115 DCS)	Jan 13–Feb 04	Feb 01*	312°5	299°	−15°	M*
χ -Capricornids (114 DXC)	Jan 29–Feb 28	Feb 13*	324°7	315°	−24°	L*
April Piscids (144 APS)	Apr 20–Apr 26	Apr 22	32°5	9°	+11°	L
ϵ -Arietids (154 DEA)	Apr 24–May 27	May 09	48°7	44°	+21°	L
May Arietids (294 DMA)	May 04–Jun 06	May 16	55°5	37°	+18°	L
α -Cetids (293 DCE)	May 05–Jun 02	May 20	59°3	28°	−04°	M*
Arietids (171 ARI)	May 14–Jun 24	Jun 07	76°6	42°	+25°	H
ζ -Perseids (172 ZPE)	May 20–Jul 05	Jun 09*	78°6	62°	+23°	H
β -Taurids (173 BTA)	Jun 05–Jul 17	Jun 28	96°7	86°	+19°	M
γ -Leonids (203 GLE)	Aug 14–Sep 12	Aug 25	152°2	155°	+20°	L*
Daytime Sextantids (221 DSX)	Sep 09–Oct 09	Sep 27*	184°3	152°	0°	M*

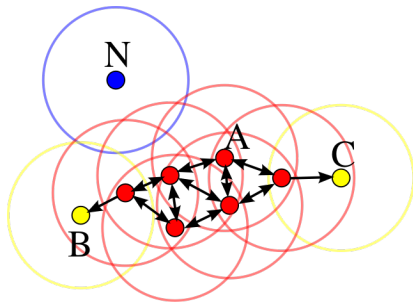
Cluster algorithm

- ▶ We see new showers and outbursts from time to time:
 - ▶ 2014 May Camelopardalids
 - ▶ 2014 Phoenicids
 - ▶ 2016 γ Draconids
- ▶ Former intern Josh Burt wrote a script to automatically detect clusters of 5 or more meteors in 3 day intervals (Burt et al. 2014):

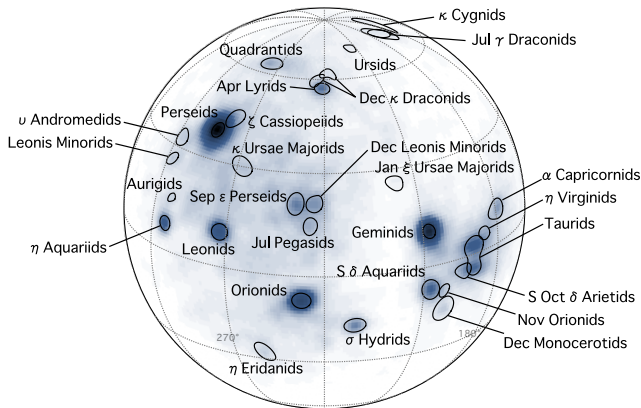


Shower surveys

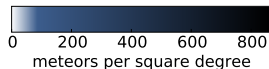
- ▶ Shower surveys are a fun way to begin working with meteor data
- ▶ Former MEO intern Glenn Sugar used density-based cluster algorithm DBSCAN to automatically detect showers in the all-sky data (Sugar et al. 2017)



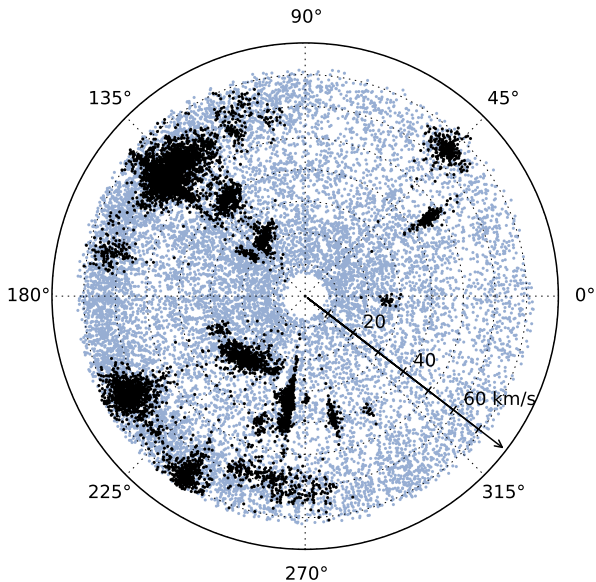
Shower surveys



Meteor radiant density in Sun-centered ecliptic coordinates. Detected showers are labeled.

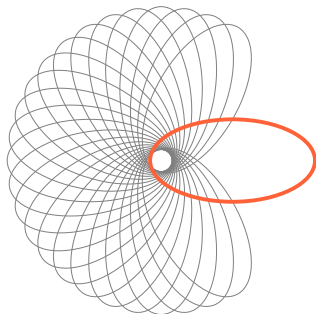


Shower surveys

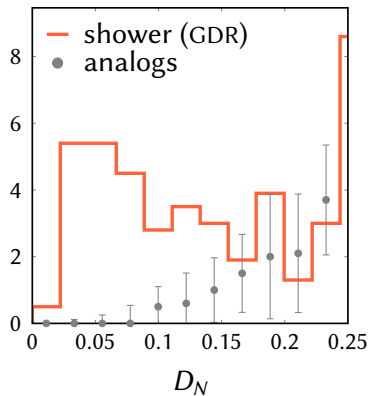
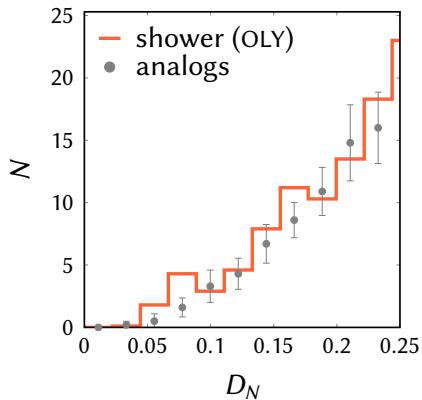


Shower significance

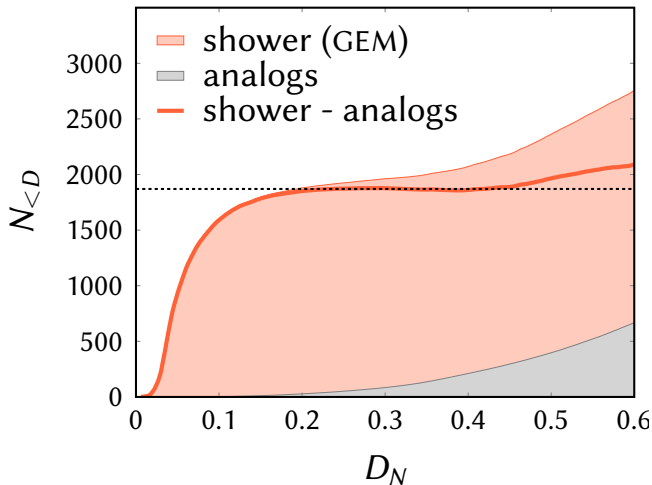
- ▶ The sporadic background is not isotropic
- ▶ False positives for shower association depend on nearby sporadics
- ▶ But showers are shorter-lived than sporadics
- ▶ So how does clustering around a given orbit (measured by D_N) vary by time of year?



Shower significance



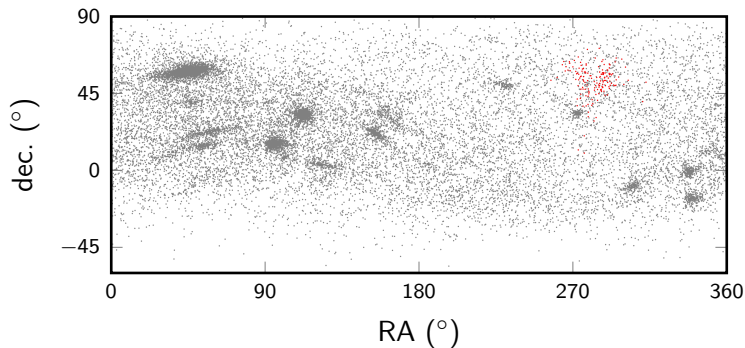
Shower significance



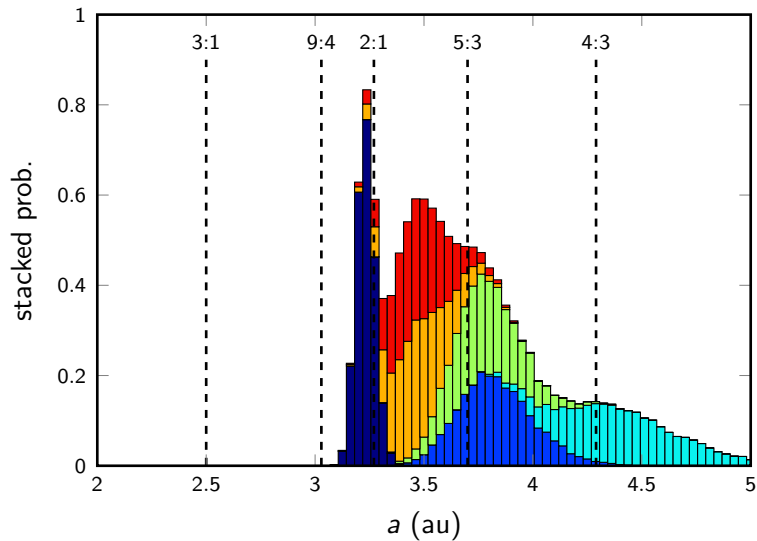
Individual showers

κ Cygnid outburst in 2014

- ▶ Diffuse radiant makes membership determination tricky

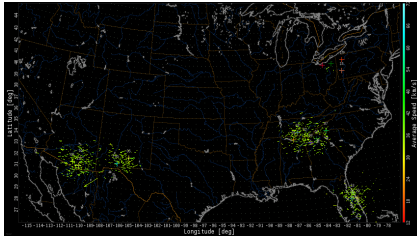


Individual showers

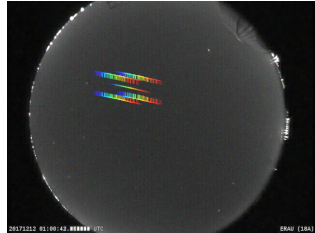


Shower reports

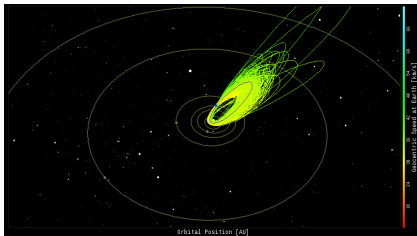
ground tracks for all-sky Geminids



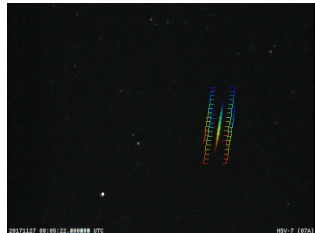
sample all-sky Geminid



orbits of all-sky Geminids

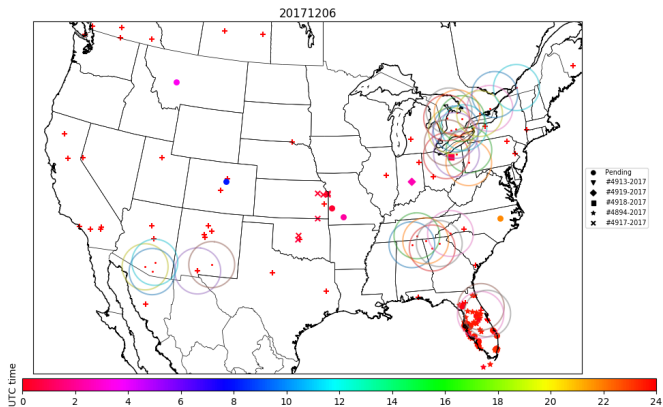


sample wide-field Geminid

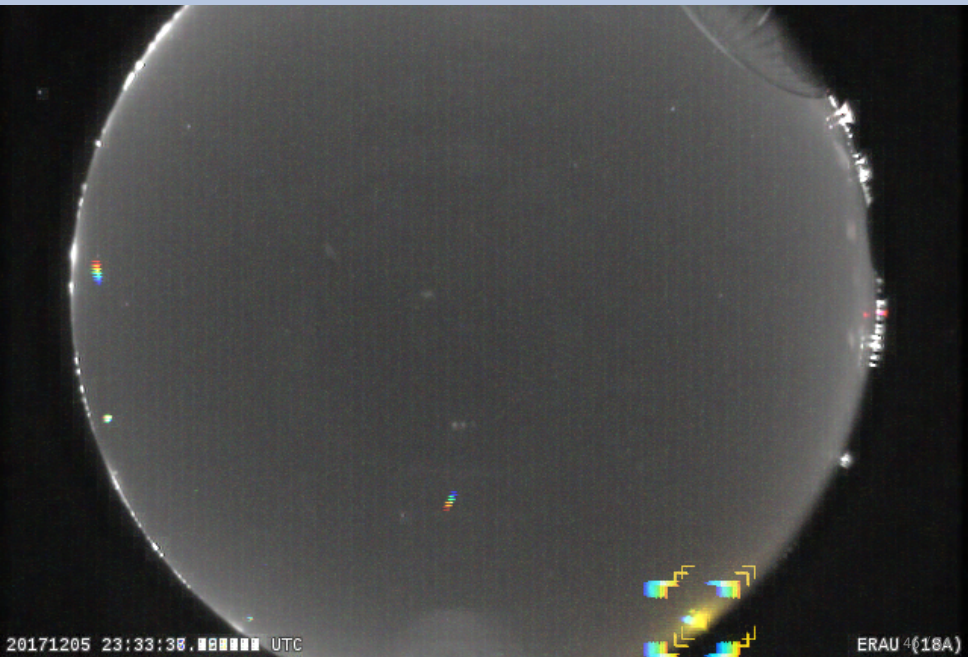


"Skyfalls"

Map of observer reports from amsmeteors.org



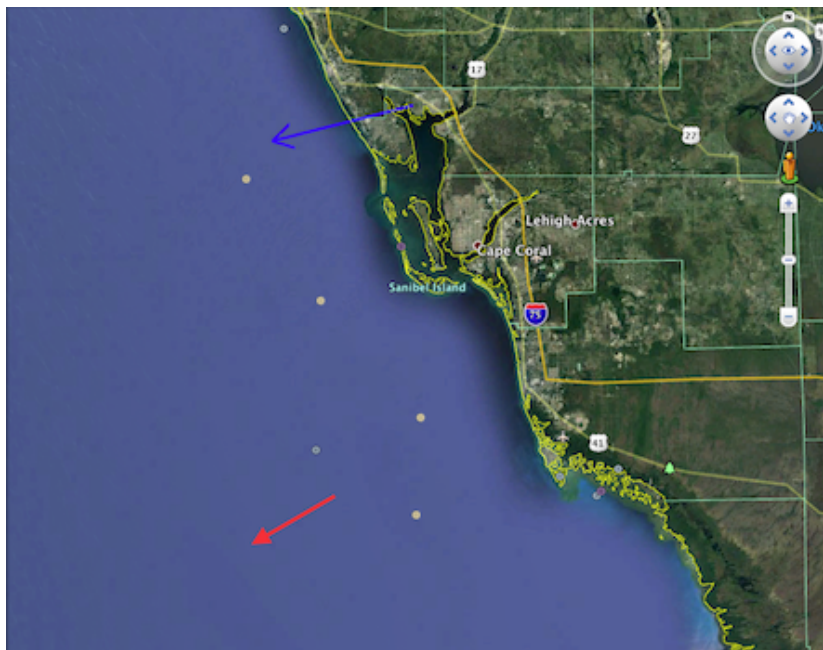
"Skyfalls"



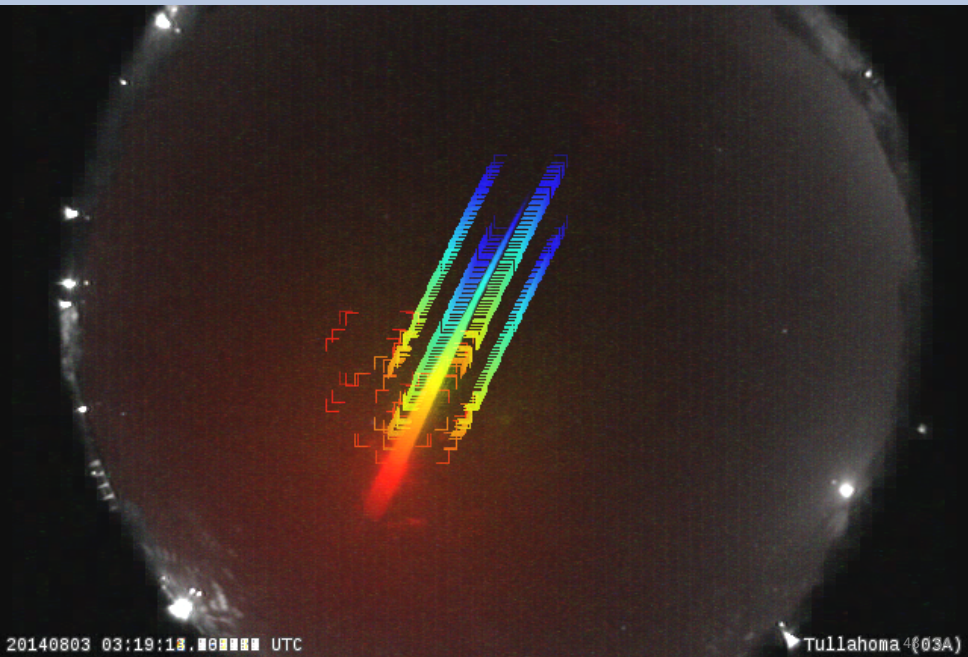
20171205 23:33:38.000000 UTC

ERAU 4(18A)

"Skyfalls"



Meteorite falls



20140803 03:19:13.00 UTC

Tullahoma 403A

Meteorite falls

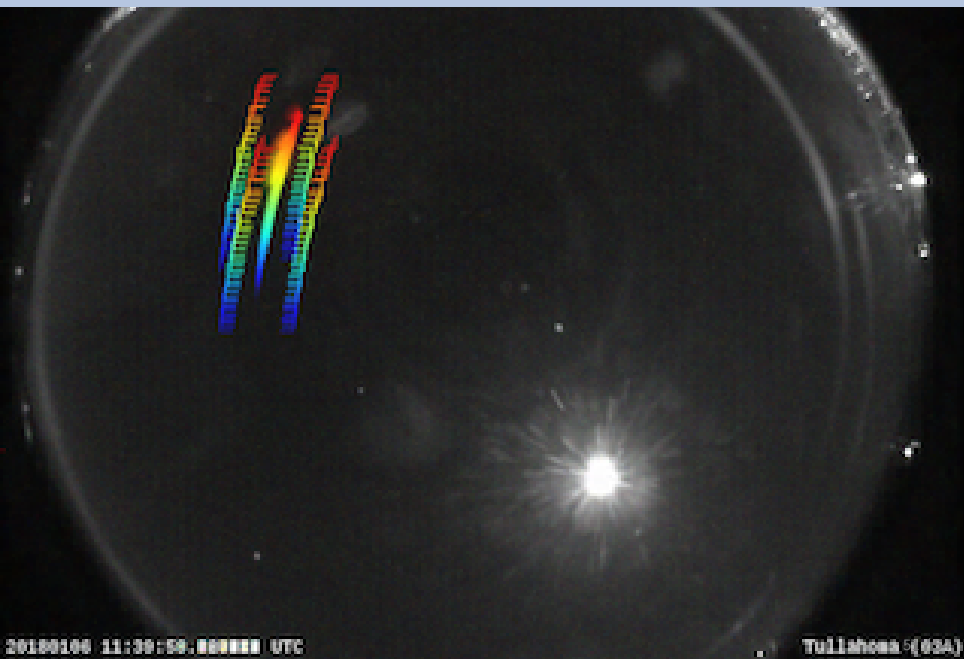


Meteorite pieces found near Addison, AL by Stephen Beck, Tommy Brown, Jerry Hinkle, and Robert Woolard. Credit: Tommy Brown

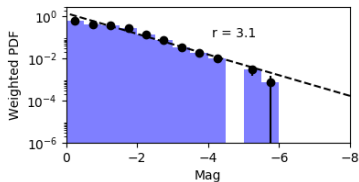
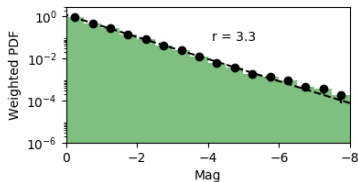
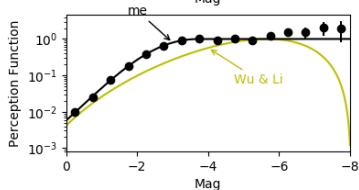
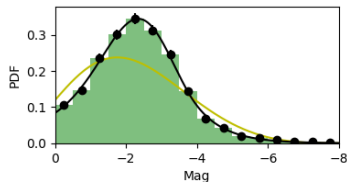
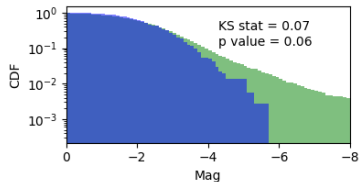
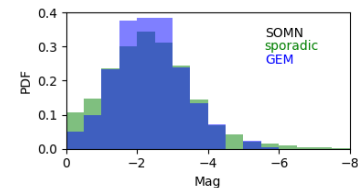
Potential projects: Cloud detection

- ▶ Clouds are another bias (seasonal effect)
- ▶ Can partially or wholly obscure the sky
- ▶ Appearance varies by site and moon phase
- ▶ Historical cloud cover data only partially useful
- ▶ Opportunity to try machine learning?

Potential projects: Saturation correction

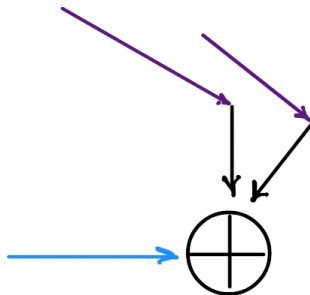


Potential projects: Mass indices



Potential projects: Slow shower survey

- ▶ We generally use *geocentric* radiant to identify meteor showers
- ▶ This can increase the apparent dispersion for slower showers
- ▶ Could survey using heliocentric radiant instead



Summary

- ▶ Embry-Riddle and UCF host two of the newest cameras in the NASA All Sky Fireball Network (welcome!)
- ▶ The data from this network are used in a variety of tasks and projects
 - ▶ shower detection
 - ▶ shower surveys
 - ▶ shower reports
 - ▶ bright bolide analyses (“skyfalls”)
 - ▶ meteorite hunts
- ▶ The data can be used for student research projects. Potential projects include:
 - ▶ cloud detection
 - ▶ saturation correction
 - ▶ mass indices
 - ▶ a survey of slow showers